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Title: IN SITU GAMMA RADIATION SURVEY AT ARA-23 AND ARA-24

Summary:

This EDF presents the results of an in situ radiation survey that was conducted at two WAG 5 sites, ARA-23 and ARA-24. These surveys were conducted as part of the Operable Unit 5-12 Remedial Investigation/Feasibility Study and were to measure and determine the detailed distribution and concentration of Cs-137 in the surface soil.

ARA-23 is a large windblown soil contamination area surrounding both the ARA-I and ARA-II facilities. This contamination was a result of the SL-1 accident and its subsequent cleanup activities. ARA-24 is a windblown contamination area resulting from the reactor operations at the ARA-III facility.

The INEEL Environmental Monitoring personnel using a vehicle-mounted scillinator with a GPRS system successfully completed the ARA-23 and ARA-24 in situ radiation surveys. Over 69,000 measurements were collected at ARA-23 and over 13,000 measurements were collected at ARA-24. These data were converted to estimates of in situ Cs-137 concentrations based on methods developed and adapted by INEEL radiation measurements personnel. Converted data were compiled into maps showing the quantitative distribution of Cs-137 across these sites.

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# RESULTS OF THE IN SITU GAMMA RADIATION SURVEY AT ARA-23 AND 24

## INTRODUCTION

This report summarizes the in situ radiation survey conducted at the Auxiliary Reactor Area (ARA)-23 and ARA-24 sites during July through September, 1997 as part of the Waste Area Group (WAG) 5, Operating Unit 5-12 (OU 5-12) Remedial Investigation/Feasibility Study (RI/FS). The specific purpose of the investigation was to determine the detailed distribution and concentration of Cs-137 soil contamination at the ARA-23 and ARA-24 sites. This investigation supports the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) activities at Idaho National Engineering and Environmental Laboratory (INEEL), as implemented under the Federal Facility Agreement/Consent Order (FFA/CO).

## BACKGROUND

The ARA facilities, originally called the Army Reactor Area, were constructed in the 1950s to support of the Army Nuclear Program. The Army program was phased out in the early 1960s, and the group of facilities became the Auxiliary Reactor Area in 1965. Since then, all the reactors have been removed from the ARA facilities. From 1966 to 1989, work at ARA included a variety of technical support services for INEEL research and development programs that used the metallurgy laboratory, instrument development laboratory, or the hot cell facility. There have been no active operations conducted at ARA since 1989. Decontamination and decommissioning of the ARA-I/II and ARA-III facilities is currently in progress.

The ARA-23 site is a large area of primarily windblown contamination around the ARA-I and ARA-II facilities that resulted from the SL-1 reactor accident in 1961 at ARA-II. During this accident, the reactor vessel and building were severely damaged and highly contaminated. Much of the contamination still detected around the ARA-I/II facilities was disseminated either during the accident or the subsequent massive cleanup effort of the reactor and building structure. Although the accident occurred within the ARA-II facility, portions of the ARA-I facility were contaminated because it was used as a staging and operations area for the cleanup effort. Transport of debris to the SL-1 burial ground, located approximately 1600 feet northeast of the reactor site, also spread contamination in the area. The contamination is believed to be generally limited to the upper few inches of surface soils. The ARA-23 boundary encompasses more than 240 acres, of which approximately 40 acres were selected for additional characterization based on a 1990 aerial radiation survey and on interpolation of widespread sampling results.

The ARA-24 site encompasses all of the potentially contaminated surface soils associated with ARA-III facility, excluding the ARA-12 site. The surface soil contamination at the ARA-III

facility most likely originated from the process and ventilation stacks at the facility. The Army Gas Cooled Reactor Experiments were conducted from 1959 to 1961 at ARA-III. Then the facility was converted to support the Mobile Low Power Reactor tests conducted at ARA-IV until 1965. Support structures, including laboratories and office space were utilized until the facility was shut down in 1989. The ARA-12 evaporation pond is also located nearby. The total area is approximately 10 acres and extends outward from the facility, primarily to the northeast.

Cs-137 has been chosen as the indicator radionuclide at both ARA-23 and ARA-24 because it is known to be widespread and because its 662 keV gamma-ray is readily detected by field screening equipment. Sr-90 also occurs widely at these sites and is equally important from a risk assessment standpoint. However, as a pure beta emitter, Sr-90 is more difficult to detect using field screening methods. Previous WAG 5 studies show that Cs-137 and Sr-90 are co-located, suggesting that Cs-137 may be a valid qualitative indicator for Sr-90 distribution. However, during the SL-1 cleanup, Sr-90 was found beyond the limits of the Cs-137 distribution, which indicates that their co-location may not be universal. For the purposes of this report, it must be emphasized that the analysis herein applies strictly to Cs-137 on the assertion that all detected gamma radiation above background is derived from Cs-137 decay. Any connection with Sr-90 distribution and concentration must be established independently.

## INVESTIGATION OBJECTIVES

The OU 5-12 RI/FS Work Plan (DOE/ID-10555) identifies the horizontal and vertical extent of the Cs-137 contamination at the ARA-23 and ARA-24 sites as data gaps. The work plan calls for the soils to be sampled in three phases: 1) a sodium iodide detector field survey for gamma radiation; 2) statistical analysis of field results and laboratory gamma spectroscopy results; and 3) ranked-set sampling as described in the Field Sampling Plan (Appendix D of the work plan), if required by the results of 1 and 2. This report presents the results of the Phase 1 Gamma Radiation Survey.

A specific objective of the work plan is to define the extent of the Cs-137 soil contamination that exceeds 17 pCi/g. The 17 pCi/g limit is based on the residential exposure scenario assumed to begin 100 years in the future after the mandatory institutional control period has expired. The results of this Phase 1 Gamma Radiation Survey will be evaluated by the regulatory agencies and DOE. Future decisions regarding remedial activities at the ARA-23 and ARA-24 sites will be based on this study in conjunction with soil sample results, data quality and usability, process knowledge, and other information available to decision makers. Potential applications of this analysis include:

1) defining further characterization activities,

2) defining an interim action or housekeeping activity,

3) providing data for the WAG 5 BRA and the FS alternative development,

4) improved estimates of contaminated material volume, and

5) providing the framework for future remedial actions under the WAG 5 comprehensive Remedial Action/Remedial Design phase.

## METHOD

The in situ gamma radiation survey involves measuring gamma radiation from a position above the contaminated soil surface. Figure 1 shows the typical measurement geometry for an in situ gamma-ray detector. Radionuclides within the soil emit photons. The soil dissipates photon energy through absorption and scattering processes, but some energy escapes the soil zone and radiates outward to interact with the gamma-ray detector. The detector "counts" these interactions to give a measure of the radioactivity present. The number of gamma rays "counted" at a given measurement point depends on several factors as listed in Table 1. The factor G contains the desired information on radionuclide concentrations.

***Table 1.*** *Factors affecting in situ measurement of radionuclides*

| Symbol | Factor |
|---|---|
| $\Omega$ | sensor field of view |
| $\rho$ | soil density |
| $\gamma$ | gamma-ray energy |
| E | detector efficiency |
| G | amount and distribution of radionuclide in soil |

### Equipment

One of the distinct advantages of in situ measurement relates to the sensor field of view. The field of view may be made quite large through appropriate sensor design, permitting the detector to count photons emitted over an extended area. Thus, even for low radionuclide concentrations, a large number of photon-detector interactions occur and the measurement may be made rapidly, e.g. in one second. At this speed it becomes possible to fully map radionuclide concentrations over a large area by attaching the detector to a mobile system and traversing the area of interest.

The ARA-23 and ARA-24 areas were mapped using two types of in situ detectors: the INEEL Environmental Monitoring Global Positioning Radiometric Scanner (GPRS) and a portable Germanium spectrometer (Ge-spectrometer). The GPRS consists of a large area plastic scintillation detector mounted on the front of a HumVee all-terrain vehicle equipped with global positioning navigation instruments. The scintillation detector is permanently mounted to

maintain a constant detector-to-ground distance of 1 meter. At this elevation, the scintillation detector has an approximately 25 feet diameter field of view.

Ge-spectrometer measurements were collected in areas inaccessible to the GPRS and at a selected set of calibration points. During a standard in situ measurement, the Ge-spectrometer sets on a tripod that maintains a constant detector-to-ground distance of 1 meter. At this elevation the Ge-spectrometer has approximately the same field of view as the scintillation detector, i.e. about 25 feet in diameter. Measurement locations are determined separately through conventional surveying techniques. Several auxiliary Ge-spectrometer measurements were made using an alternate measurement geometry. These will be described in a later section.

**Calibration**

In situ Ge-spectrometer measurements have been routinely conducted for many years and the protocol for converting raw count data to radionuclide concentration estimates is well developed. Attachment 1 contains details of the conversion process used for the Ge-spectrometer measurements at ARA-23. The method employed in these calculations assumes that the radionuclide (Cs-137) is distributed in an exponentially decreasing fashion, decreasing from $A_{max}$ at the surface to $A_{max}/e$ at a depth of 4-inches (e=2.718). The analysis software reports the value $A_{max}$ at each Ge-spectrometer measurement location.

Each 1 to 2 seconds, the GPRS generates a "count" value that reflects the bulk radionuclide concentration throughout the sensor field of view, which is approximately 25 feet in diameter. Successive measurements occur as the field of view is swept over the ground surface by motion of the GPRS vehicle. Count values change in response to the spatial distribution of radionuclides in the soil. These data are quantitative in the sense that they accurately depict relative radionuclide concentration as it varies across a site. However, absolute concentration estimates can be made only after calibrating the detector. The calibration process accounts for the influence of the first four factors in Table 1 above. With these factors known, the raw count data may be interpreted in terms of the remaining factor, G, which gives an estimate of the absolute radionuclide concentration.

Two separate calibration approaches were used in the ARA surveys. Both methods require that background radiation arising from natural radionuclides be removed from raw count data prior to conversion. Background analysis is discussed in some detail below. Both calibration methods also assume constant soil density and gamma-ray energy. Specifically, the density 1.5 g/cm$^3$ is assumed for shallow, unconsolidated root zone soils. Secondly, since Cs-137 is the dominant gamma-ray emitting radionuclide at the ARA sites, gamma-ray energy is taken to be 662 keV only, which is the energy of the single gamma-ray generated during Cs-137 decay.

In the first calibration method, a Monte Carlo simulation and geometric arguments were employed to establish sensor field of view, and detector efficiency. Attachment 2 contains details of the calculations. Several items are to be noted. First, field of view and detector efficiency factors are not based on direct measurements using the GPRS scintillator. Instead,

they are based on measurements made using a similar scintillator, where geometric arguments are employed to account for differences in detector size and shielding. Second, the final conversion factor contains some uncertainty that arises from uncertainty in the scintillation detector low-level discriminator setting. In this report, GPRS data are converted based on a mid-range estimate for this setting. Third, in determining G, which gives information on both the amount and distribution of Cs-137, it is necessary to assume a distribution in order to estimate amount. Attachment 1 calculations assume uniform Cs-137 to a depth of 4-inches. In this case, the final conversion factor assumes no Cs-137 occurs below this depth. A similar set of calculations (Attachment 3) provides conversion factors for uniform distributions to 1 inch and 2 inches.

The second GPRS calibration method utilizes a 14-point Ge-spectrometer calibration profile collected within the GPRS survey area. Cs-137 concentrations along this profile are computed from the Ge-spectrometer data in the normal fashion. Then, by forming an appropriate mathematical relationship between these computed concentrations and the GPRS data along the same profile, it is possible to determine a background value and conversion factor that fits one data set to the other. When the remaining GPRS data are converted using this calibration factor, they yield concentration values consistent with the same exponentially decreasing function as defined for the Ge-spectrometer calibration profile, i.e. 1/e decrease over 4-inches.

## ARA-23 RESULTS

The results of the ARA-23 site in situ gamma radiation survey are presented in the following section. Preliminary areas of interest at ARA-23 were identified based on previous soil sample results. The in situ surveys were undertaken to further refine the details of contaminant distribution. Original survey specifications proposed data collection throughout the areas of interest at 25 feet nominal profile spacing, at an average speed of 2.5 mph, and with a data acquisition interval of approximately 2 seconds.

### Data collection

Figure 2 shows the in situ gamma radiation survey data collection pattern for the ARA-23 area with the original survey boundary noted. The ARA-23 in situ gamma radiation survey was expanded to include several areas outside the original boundary based on preliminary results. Additional data were also collected adjacent to the SL-1 Burial Ground, northeast of the preliminary boundary. Finally, several profiles were collected in a radial pattern outward from the main site to assist with background evaluation. In total, over 69,000 in situ gamma radiation measurements were collected along the black track lines in Figure 2. The map also notes areas that were temporarily inaccessible to the GPRS vehicle.

The yellow-filled circles in Figure 2 show the locations of the in situ Ge-spectrometer measurements. Eighty-eight Ge-spectrometer measurements were collected from a rocky, debris-filled zone that was inaccessible to the GPRS vehicle. A second set of measurements were taken along the Ge-spectrometer calibration profile noted in the section above.

**Bulk gamma-ray fields and background analysis**

Figure 3 shows a color intensity map depicting the bulk gamma radiation measured by the GPRS system. On this map, uncolored areas correspond with locations that are greater than 25 feet from a measurement point. In the remaining areas, color indicates the gamma-ray field intensity in counts per second (cps) according to the scale indicated by the color bar. The maximum cps value recorded anywhere was 117,961 cps. The highest gamma radiation measurements recorded were located in four distinct areas; adjacent to the old ARA reactor facilities; immediately northeast of the old ARA reactor facilities; around the northeast boundary of the SL-1 Burial Ground; and along the dirt road between the ARA facilities and the SL-1Burial Ground. The lowest gamma radiation measurements were recorded at the survey fringes and along several of the radial background profiles. Intermediate values were obtained both southwest and northeast of the reactor facilities all the way to the survey boundary. The northeast trending pattern of elevated gamma radiation is more extensive than the pattern to the southwest. The northeast trending pattern of elevated gamma radiation is also characterized by a sharp boundary on its southeast margin and a very gradual boundary on its northwest margin. This zone correlates with the prevailing wind direction at the site.

In Figure 4, the same bulk gamma radiation data are presented with a color scale intended to highlight variations in the background gamma radiation field. The RESL soil samples (circles) and WAG 5 soil samples (triangles) have been included with their Cs-137 concentrations posted in pCi/g. One can estimate local background radiation by examining cps measurements in areas adjacent to low Cs-137 results (~1 pCi/g) in the soil samples. By this method, background appears to vary mostly within the range from 1200 to 1400 cps. The observed variation probably reflects natural variations in soil chemistry, density and vegetation. A value of 1300 cps was chosen as a best estimate, in part based on results of the Ge-spectrometer calibration discussed below.

Note also the very low background gamma radiation (<1000 cps) measured adjacent to the southwest corner of the SL-1 Burial Ground. This area was disturbed during the construction of the burial ground and now contains non-native soils with relatively low natural radioactivity. In addition to illustrating the tremendous sensitivity of the GPRS equipment, this scenario illustrates the effect of human activity on background variability. Survey planning must include a set of measurements specifically designed to characterize natural background variability, identify non-representative background areas and avert selection of a biased background radiation level.

**Conversion to activity concentration**

Figure 5 shows data along the Ge-spectrometer calibration profile (see Figure 2). In this chart, continuous GPRS data in cps are shown in blue. The red profile presents the Ge-spectrometer data results (in pCi/g) using the 4-inch exponential distribution model.

The relationship between the GPRS count data and the Ge-spectrometer data may be written as;

$C = (cps - bg) * K$ where:

$C$ = Cs-137 concentration based on the 4-inch exponential model,

*cps* = raw count data from the GPRS scintillator,

*bg* = the background count rate, and

$K$ = a linear conversion factor that scales cps to pCi/g.

These data were entered into a spreadsheet that permitted iteration of the factors *bg* and $K$ to obtain a fit between the two data sets. Figure 6 shows the results from this procedure, where the values *bg* = 1300 cps and $K$ = .019 (pCi/g)/cps have been determined. The background value falls near the middle of the observed background range and has been adopted as the best value for conversion of the GPRS data for all distribution models.

Table 2 summarizes the conversion factors developed for converting GPRS count values to Cs-137 concentrations in pCi/g at ARA-23. Each set of factors corresponds to a different assumption regarding the distribution of Cs-137 within the soil. Since the distribution model can affect the quantification process by as much as a factor of 2.5, it should be chosen based on supporting information if at all possible.

***Table 2.*** *Conversion factors for GPRS data collected at ARA-23.*

| Cs-137 Distribution Model | K (pCi/g)/cps | Background (cps) | Calibration Method |
|---|---|---|---|
| 4-inch uniform | 0.0091 | 1300 | theoretical |
| 2 inch uniform | 0.0136 | 1300 | theoretical |
| 1 inch uniform | 0.0228 | 1300 | theoretical |
| 4-inch exponential* | 0.019 | 1300 | direct measurement |

* Graphics depicting results from the 4-inch exponential model (Figures 6 and 10) show Cs-137 concentrations *at the ground surface* ; it is understood that concentration decreases exponentially from this maximum value.

GPRS count data were converted to Cs-137 concentrations based on each set of conversion factors given in Table 2. Figures 7 through 10 present these results. The colored circles in Figure 10 show concentration values generated from Ge-spectrometer data as well, since these values are based on the same 4-inch exponential distribution model. Circle coloring uses the same concentration scale as for the main body of GPRS data. Note in particular the close fit between the GPRS data and the Ge-spectrometer calibration line. This is an expected result since these points were used to tie the two data sets together (see Figure 6).

**Discussion of distribution models**

The appropriate selection of a Cs-137 distribution model is critical at ARA since DOE may potentially remediate the ARA-23 site to a specific cleanup level. Preliminary negotiations between the stakeholders indicate that the cleanup level may be 17 pCi/g. Figure 11 illustrates the Cs-137 distribution model's effect on the size of a potential cleanup operation aimed at removing all soils above 17 pCi/g. The color coded outlines on Figure 11 show the boundary between Cs-137 exceeding 17 pCi/g (interior) in soil and Cs-137 less than 17 pCi/g (exterior) in soil. An approximate comparison in the acreage and volume of cleanup for the different models is given in Table 3. These calculations reflect soil areas within the originally defined ARA-23 survey boundary only. The volume estimates do not reflect construction equipment limitations, vegetation removal complications, or potential cross contamination during excavation. These may significantly increase soil volume estimates if a removal option is selected.

***Table 3.*** *Area and volume estimates for ARA-23 cleanup using different distribution models.*

| Description | Area (acres) | Cleanup Volume (cu yds) |
|---|---|---|
| survey boundary | 39.2 | - |
| >17 pCi/g Cs-137 to 1 inch depth | 30.6 | 4097 |
| >17 pCi/g Cs-137 to 2 inch depth | 23.0 | 6188 |
| >17 pCi/g Cs-137 to 4-inch depth | 14.5 | 7793 |

It is important to note that uncertainty in radionuclide depth distribution is not unique to in situ radiation measurement techniques. The most common method for estimating radionuclide concentration, soil sampling, possesses the same inherent uncertainty. Normal soil sampling activities require that a soil core be taken to a specified depth. The core is then homogenized, its radioactivity is counted, and the result is divided into the mass of the core to provide a concentration value in pCi/g. This method will underestimate the maximum concentration in the core unless the core has truly uniform radionuclide distribution. The problem can only be averted by subdividing the core into discrete depth intervals and counting them separately, which is a difficult and expensive operation to perform in unconsolidated soil.

In situ measurement techniques include methods for addressing the depth distribution of radionuclides in some cases. In the case of Cs-137, a K x-ray emitted in the Cs-137 decay chain permits a comparison of attenuation between photons having very different energies. The K x-ray and the 662 keV gamma ray are emitted in known ratios. The relative numbers of each photon that escape the soil and are detected by a Ge-spectrometer give an indication of the depth from which they arise. For a deep soil source, virtually no K x-rays escape the shielding effect of the soil while gamma-rays are still detected. From a surface source, K x-rays and gamma-rays are detected in very nearly the proportion they are emitted.

A special set of Ge-spectrometer measurements were collected to evaluate depth distribution. These measurements were made along the Ge-spectrometer calibration profile using a detector height of six inches. These measurements showed K x-ray/662 keV gamma-ray peak ratios ranging between 0.15 and 0.25, with an average near 0.20. Table 4 below gives theoretical K x-ray/662 keV gamma-ray peak ratios for various depth distributions (see also Attachment 4). The average measured peak ratio is consistent with a uniform distribution to about 1 inch. This analysis also strongly indicates that the Cs-137 contamination begins very near the ground surface and is not overlain (and therefore shielded) by any significant amount of clean soil. These conclusions apply strictly to the windblown portion of the ARA-23 contamination plume where the calibration measurements were made.

***Table 4.*** *X/gamma ratios for Cs-137 at different depth distribution.*

| Source Uniform Down to (in) | Theoretical x/gamma ratio |
|---|---|
| 0.5 | 0.32 |
| 0.7 | 0.26 |
| 0.9 | 0.21 |
| 1.2 | 0.17 |
| 6.0 | 0.077 |

A truly uniform distribution of Cs-137 throughout any depth is, of course, highly unlikely. Wind-deposited contamination that has been reworked by percolating groundwater might exhibit more of an exponentially or linearly decreasing concentration-depth profile. Attachment 4 gives a theoretical x/gamma peak ratio of 0.25 for Cs-137 concentrations that decrease linearly to a depth of 1.1 inch, which is at the maximum of the observed range. The distinction between the linear and uniform case cannot be made with any certainty. In fact, different distributions are very likely to occur in the various distinct settings such as the undisturbed desert, roadways or the rock piles.

Recent samples collected on the perimeter of the ARA-23 boundary support the thin contamination layer model. These samples were segregated into two depth intervals, 0 - 6 inches and 6 - 24-inches. Results have not yet been thoroughly analyzed, but they clearly show a marked decrease in Cs-137 soil concentrations below 6 inches.

**Comparison between in situ methods and sampling**

Figure 12 shows a summary of Cs-137 concentration data, including the GPRS data converted, using the 1 inch uniform distribution model, Ge-spectrometer data for the rock pile area converted to a 1 inch exponential distribution model, and sampling results based on 6-inch cores. Each data set has been plotted using an identical color scheme as shown by the color bar.

The Ge-spectrometer data for the rock pile show a clear continuation of the concentration trend observed for the main Cs-137 plume to the northeast, although a slight discontinuity and trend

variation is observed at the northeast boundary between the two data sets. A more pronounced discontinuity occurs at the southwest boundary. Here, the rock pile data reveal a broad concentration gradient adjacent to much lower, more uniform concentrations indicated by the GPRS data. The discontinuous boundaries may be due in part to the Ge-spectrometer analysis model which cannot account for the uneven rocky surface in the rock pile area and which may overestimate the depth extent of Cs-137. It is also quite reasonable to expect a difference in Cs-137 distribution between these areas due to differences in environmental processes and human activities over many years.

Soil sample data corroborate the general trends and concentration estimates determined from the in situ gamma radiation measurements. Figure 13 shows the quantitative comparison between the in situ gamma radiation survey estimates and sampling results in greater detail. The soil sample data in Figure 13 have been arranged in order of increasing concentration. The soil samples and in situ gamma radiation estimates follow the same general trend up to about 25 pCi/g. Some exceptions occur, primarily in the older RESL soil samples which tend to report Cs-137 concentrations greater than the in situ gamma radiation survey data. The WAG 5 soil samples agree more closely with the in situ gamma radiation survey data but tend to report lower concentration than the in situ survey data. Consistently low values from soil sample results may reflect the averaging that occurs when sample cores extend into relatively clean soils beneath the main layer of contamination.

The two data sets become erratic when the Cs-137 concentration exceeds 25 pCi/g. One explanation for this phenomenon is that the high level Cs-137 contamination is heterogeneous on a relatively fine scale, i.e. much of the radioactivity emanates from a small percentage of soil particles spaced some finite distance apart within the contaminated zone. The sample cores, which are only an inch or so in diameter, can produce highly fluctuating results depending on whether a sample location coincides with one or more hot particles. The in situ method, which averages Cs-137 activity over a 25 feet diameter, does not exhibit these erratic fluctuations. The key factor in determining whether a measurement method will produce erratic results or smooth results is the scale of the Cs-137 heterogeneity compared with the scale of the measurement method. If this hypothesis is correct, the ARA-23 data suggest that Cs-137 heterogeneity occurs on a scale greater than an inch and less than 25 feet, at least in the areas of elevated radioactivity. It is not clear why this phenomenon is observed only in the areas of elevated radiation. Cs-137 particles may be distributed on a finer scale in the low radioactivity areas located away from the reactor site. It is reasonable to expect that the scale of particle heterogeneity depends on the mechanism of Cs-137 deposition, e.g. windblown, air fallout, groundwater transport, etc. If true, measurement of this scale may prove useful for evaluating the history of soil contamination sites. This heterogeneity may not be significant if it occurs at concentration above the cleanup limit.

## UNCERTAINTY CONSIDERATIONS

Concentration uncertainty caused by the unknown Cs-137 depth distribution has been discussed already in detail. Two other sources of uncertainty require some additional treatment here.

Attachment 1 states that the precise value of the low-level discriminator for the GPRS scintillator is unknown and that this leads to a +40% to -20% uncertainty in the calculated conversion factor for the uniform distribution model. In fact, the 4 inch uniform factor may be anywhere between 0.0069 (pCi/g)/cps to 0.0133 (pCi/g)/cps. Factors for the 1inch and 2 inch Cs-137 distribution models are then calculated as a correction to the 4 inch base model. This leads to a total possible range for *K* from 0.0069 to 0.0333, accounting for all sources of uncertainty. Thus, the corresponding range in the size of the Cs-137 plume exceeding 17 pCi/g may be even greater than depicted in Figure 10.

The Cs-137 depth analysis presented in a previous section provides strong evidence for preference of the 1 inch or 2 inch models over the 4-inch model. Additional measurements or careful sampling may provide further basis for selecting a particular distribution model, thus eliminating a major uncertainty source. Laboratory measurements with the GPRS scintillator and development of a method for precisely defining the low-level discriminator can greatly reduce the second uncertainty source.

A final source of ambiguity arises from the choice of a background radiation level. Although the methods outlined for adopting an appropriate value are well supported, it is possible that background may range somewhat above or below 1300 cps. Figure 14 provides an illustration of the background effect on final concentration estimates. As in Figure 11, plotted outlines mark the limit of soil contamination exceeding 17 pCi/g. Differences between the boundary locations reflect changes in the assumed background from 1200 cps to 1400 cps. This analysis uses a *K* factor of .019 (pCi/g)/cps. Higher K factors produce greater movement of the contamination boundary, lower K factors produce lesser movement. Overall, the background effect is relatively small, with the greatest changes occurring along gentle concentration gradients. Conversely, virtually no change occurs over steep concentration gradients.

## ARA-24 RESULTS

Processing and analysis of ARA-24 GPRS data followed the ARA-23 procedure. This section provides a succinct account of the major results at ARA-24. For greater discussion, see above.

### Data Collection

Approximately 13,000 data points were collected by the GPRS system at ARA-24 following the same approach as described above for ARA-23 (Figure 15). Several gaps remain between the pre-defined survey boundary and the limit of data collection, particularly in the northeast portion of the site. However, the majority of ARA-24 shows little or no increase in radioactivity above background and the remaining data collection was suspended in favor of extending the ARA-23 survey. No Ge-spectrometer measurements were made at ARA-24.

**Bulk gamma-ray fields and background analysis**

Figure 16 shows a color intensity map depicting the bulk gamma radiation measured by the GPRS system at ARA-24. Soil contamination at ARA-24 is much less widespread and at lower concentrations than observed at ARA-23. Only the extreme southwest portion of the site exhibits any significant elevation in radiation levels. The vast majority of the site shows radiation levels at 1300 cps or less. The maximum count value recorded at ARA-24 was 14,645 cps, compared with 117,691 cps at ARA-23.

Background variation is highlighted in Figure 17. The central portion of the site formerly occupied by the ARA III facilities corresponds with slightly depressed background values (<1200 cps) compared with non-facility locations. The background depression is interpreted to result from human alterations of the shallow soil zone associated with facility operations and/or decontamination and decommissioning of ARA III. A background radiation level of 1250 cps was adopted by inspection of the non-facility portions of the ARA-24 survey data.

**Conversion to activity concentration**

The 1 inch uniform distribution model was used to convert the ARA-24 GPRS count data to estimates of Cs-137 activity concentration on the basis that this surficial distribution is appropriate for windblown deposition. Figure 18 presents results of this conversion. Note that contamination exceeding 17 pCi/g is confined to a small area (~ 1 acre) in the southwest portion of the site. The contamination area is bounded on all sides by steep concentration gradients, which indicates that the 17 pCi/g boundary will be relatively insensitive to uncertainties in the conversion factor or the adopted background level.

The contamination area begins about 100 - 150 feet southwest of the ARA-12 site, but the data indicate that the region between ARA-12 and the contamination area contains only slightly elevated (< 5 pCi/g) Cs-137. Due to inaccessible terrain, the GPRS survey terminated before reaching background radiation levels at the southwest terminus of the contamination area. Consequently the southwest limit of this contamination zone is currently undefined.

## CONCLUSIONS AND RECOMMENDATIONS

The ARA-23 and ARA-24 in situ radiation surveys were successfully completed by the INEEL Environmental Monitoring GPRS system according to the adopted specifications. Over 69,000 independent measurements were collected at ARA-23 and over 13,000 were collected at ARA-24. These data were converted to estimates of in situ Cs-137 concentrations based on methods developed or adapted by INEEL radiation measurements personnel. Converted data were compiled into maps showing the quantitative distribution of Cs-137 across these sites. The following conclusions are offered:

1. Cs-137 concentration estimates computed based on scintillation detector data were quantitatively and qualitatively consistent with historical knowledge of the ARA site activities, with independently collected in situ Ge-spectrometer measurements, and with two

suites of sample results. Discrepancies between sample results and in situ concentration estimates, which occur primarily in areas of elevated radioactivity (>25 pCi/g), are most likely due to the difference in measurement scale between the two methods.

2. The precise Cs-137 concentration estimate at any given point was shown to depend on the assumed model for Cs-137 distribution with depth. A set of accessory Ge-spectrometer measurements focused on the Cs-137 K x-ray and the 662 keV gamma-ray clearly indicate that the Cs-137 contamination is present in the first 1 to 2 inches of soil. This information greatly reduces the uncertainty in concentration estimates, but is strictly applicable only in the vicinity of the accessory measurements.

3. Cs-137 concentration estimates are subject to additional uncertainty associated with detector's unknown low-level discriminator setting. This factor produces a +40% to -20% uncertainty in the Cs-137 concentration estimates, which may be reduced or eliminated by additional laboratory measurements.

4. Concentration estimates are somewhat sensitive to the choice of a background radiation level. Accessory data were collected to specifically evaluate background radiation levels so that the uncertainty range for background is estimated to be less than ± 100 cps. This cps range corresponds to a concentration range less than ± 1 - 2 pCi/g.

5. Final maps depicting Cs-137 concentration estimates for the ARA-23 and ARA-24 sites show the distribution and concentration of Cs-137 contamination in great detail. These maps permit unambiguous identification of highly contaminated zones, contaminated roadways, sharp and gradual contamination boundaries, satellite contamination zones, and clean areas.

6. At ARA-23, in situ Cs-137 concentration estimates show the contaminated area exceeding 17 pCi/g to include from 14.5 - 30.6 acres depending on the adopted Cs-137 distribution model. Data at ARA-24 show the contaminated area exceeding 17 pCi/g to include about 1 acre, regardless of the distribution model.

In addition, the following recommendations are offered:

1. Additional Ge-spectrometer measurements or focused soil sampling would be beneficial to characterizing the depth distribution of Cs-137 across the sites. Once an appropriate model for the depth distribution is adopted, the Cs-137 concentration estimates may be recalculated with considerably reduced uncertainty.

2. Laboratory measurements and calibration of the GPRS scintillation detector would minimize the uncertainty associated with the detector's low-level discriminator setting.

3. Additional soil sampling to ascertain the relative concentration and distribution of Sr-90 to Cs-137 across the ARA-23 and ARA-24 sites would be useful to determine if the Cs-137 data is a valid indicator for Sr-90 contamination.